White dwarf initial-final mass relations and hot DQ white dwarfs

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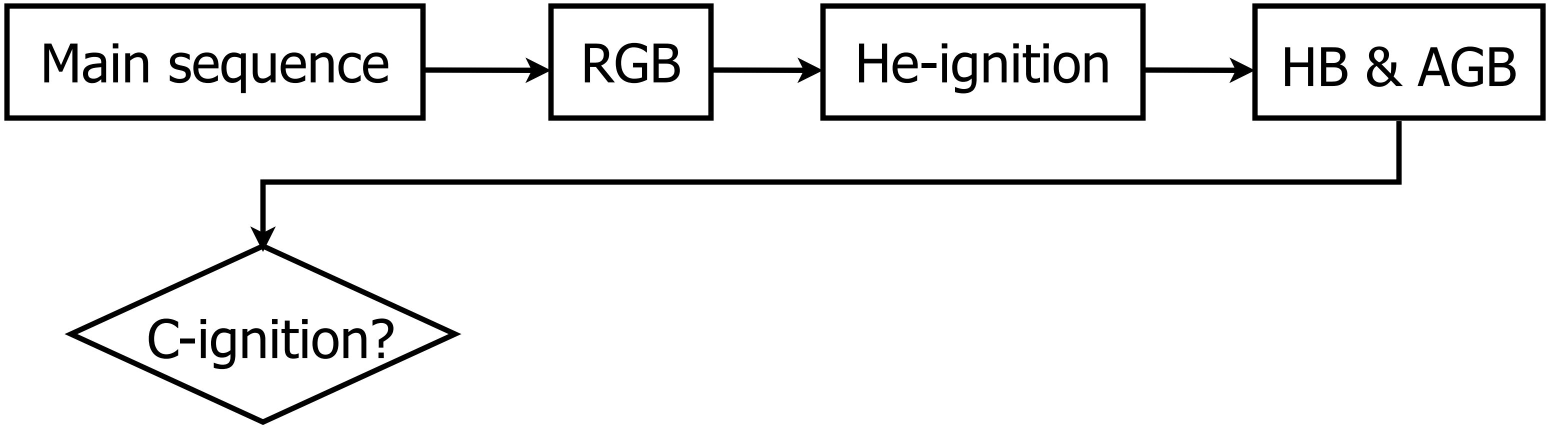
Collaborators include: Paul Dobbie (AAO), Steven DeGennaro (UT), Michael Montgomery (UT), Don Winget (UT), Patrick Dufour (Montreal), James Liebert (Arizona), Kate Rubin (UC Santa Cruz), Michael Bolte (UCO/Lick Observatory)

The ultimate fate of a star depends on its mass.

Main sequence → RGB → He-ignition → HB & AGB

The ultimate fate of a star depends on its mass.



Main sequence

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He-ignition

HB & AGB

C-ignition?

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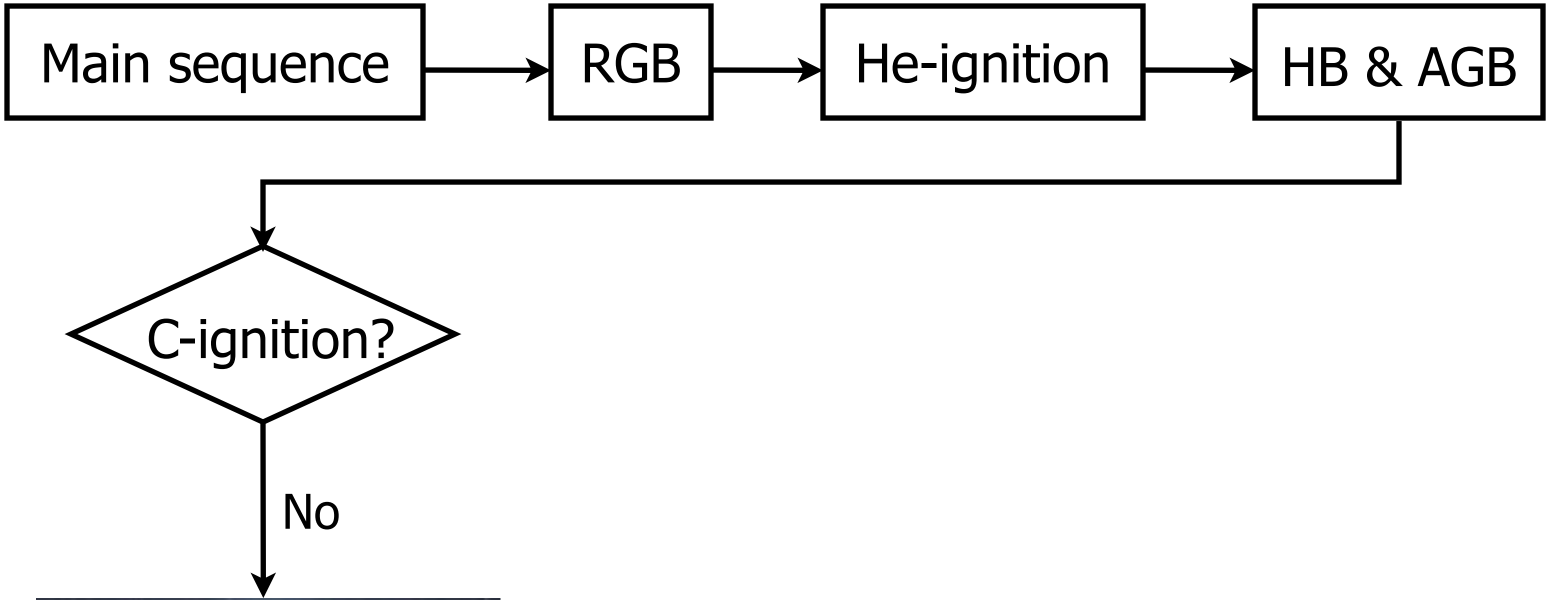

Main sequence → RGB → He-ignition → HB & AGB

C-ignition?

No

Frank Gregorio

$M_* \leq 6\text{-}8 M_\odot$

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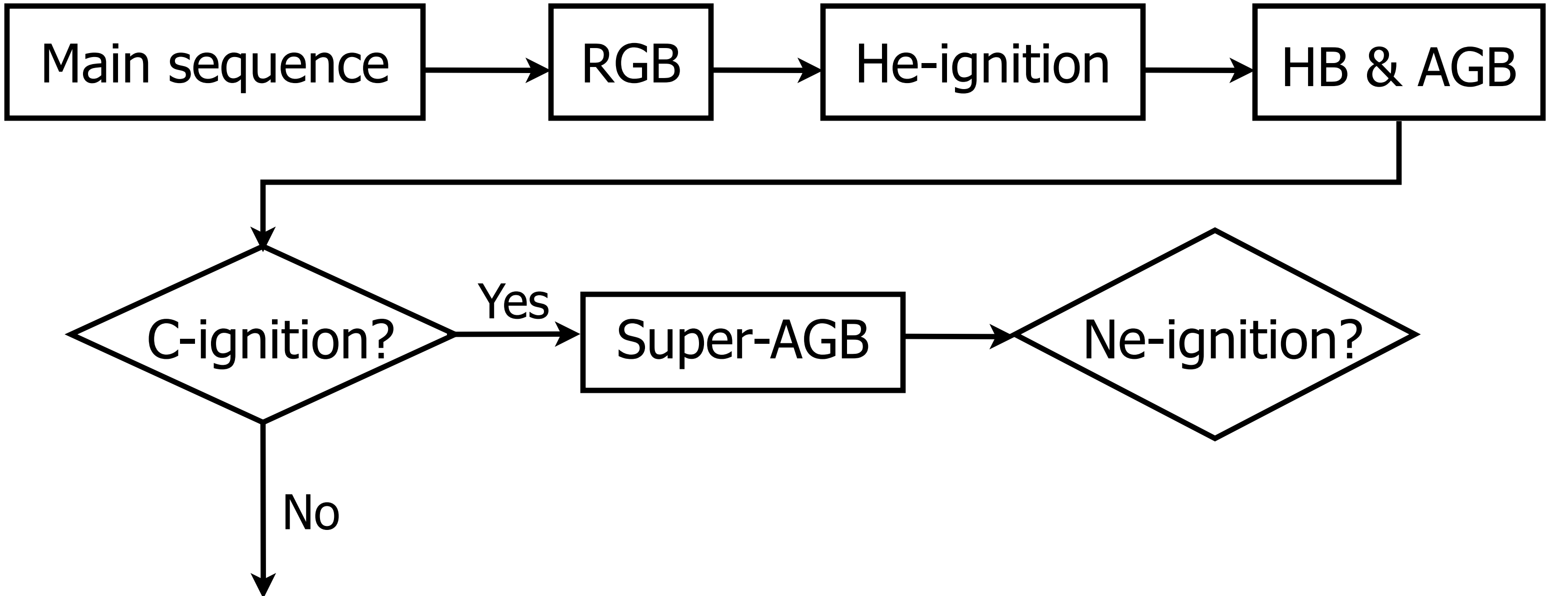

Main sequence

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Super-AGB

Ne-ignition?

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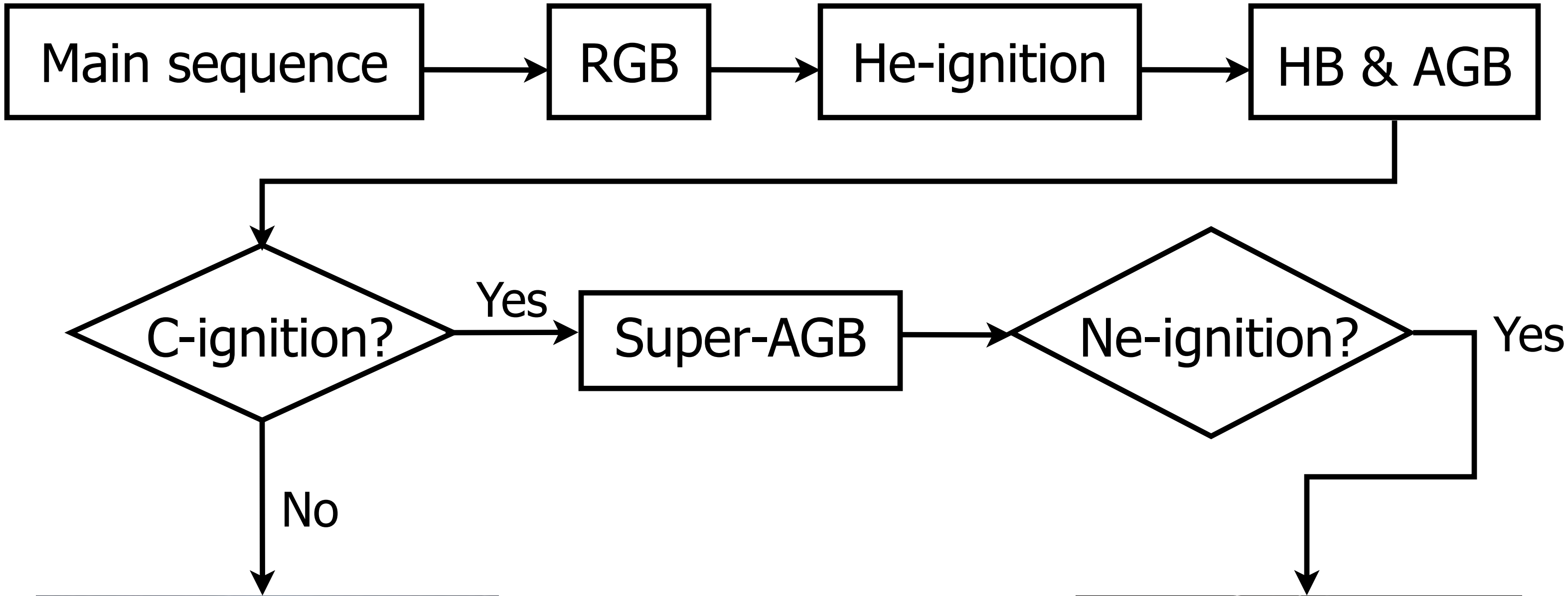

Main sequence → RGB → He-ignition → HB & AGB

C-ignition?

Yes → Super-AGB → Ne-ignition? → Yes

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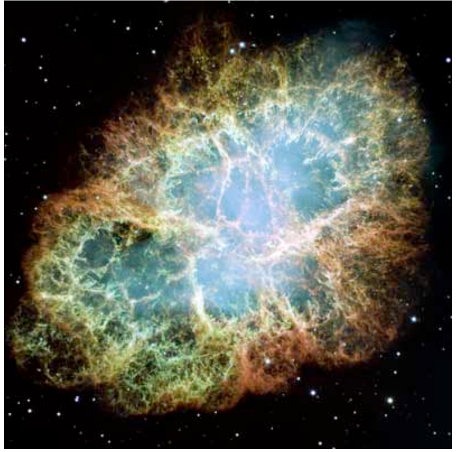

NASA, ESA, J. Hester and A. Loll

$M_* \geq 11 M_\odot$

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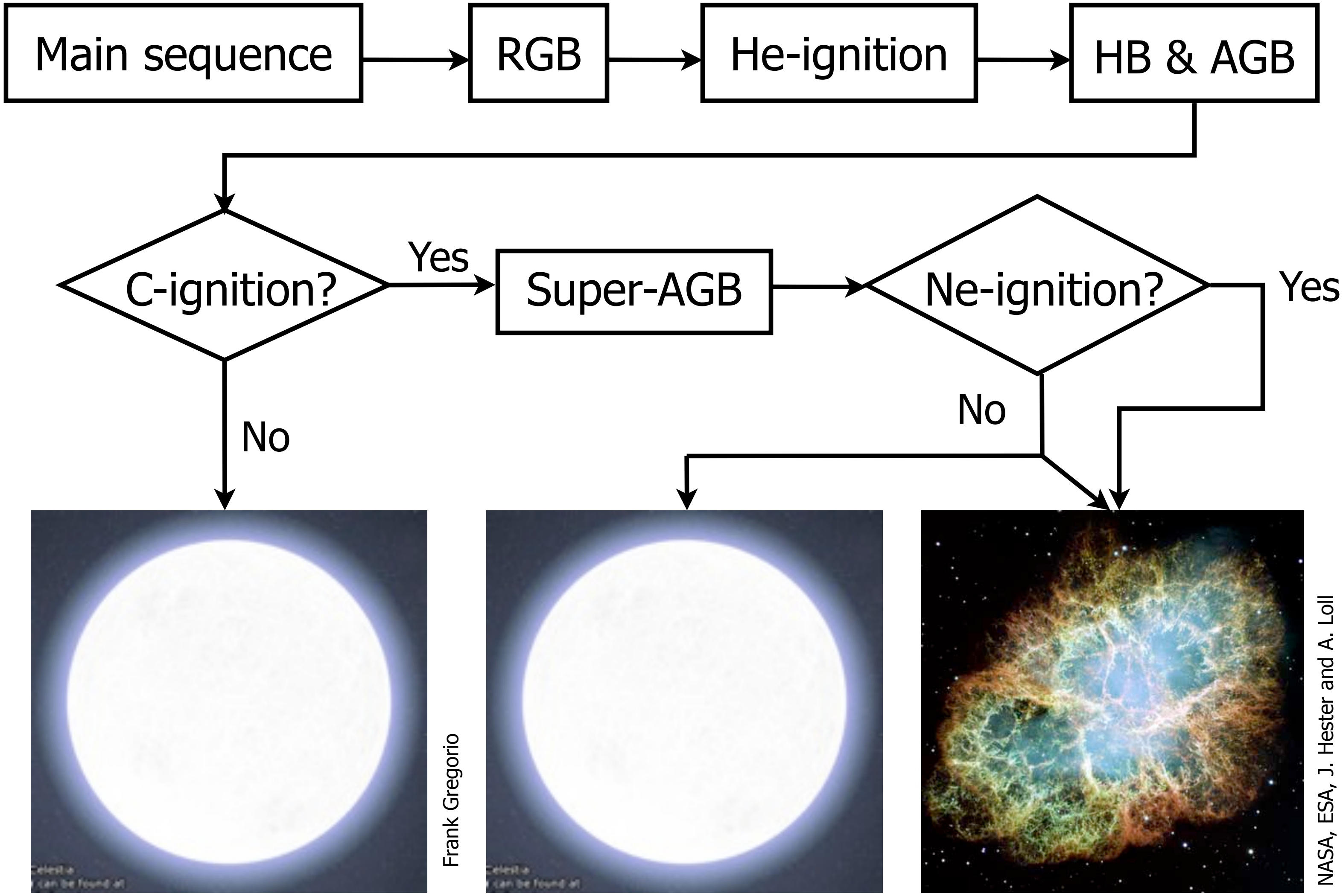

Main sequence

RGB

He-ignition

HB & AGB

C-ignition?

Yes

Super-AGB

Ne-ignition?

Yes

No

No

Frank Gregorio

NASA, ESA, J. Hester and A. Loll

$M_* \leq 6\text{-}8 M_\odot$

$7^{ish} M_\odot \leq M_* \leq 11^{ish} M_\odot$

$M_* \geq 11 M_\odot$

White dwarfs provide one observational means to determine the fate of stars.

G. Rettig

M34: Main Sequence Turnoff Mass~$4M_\odot$

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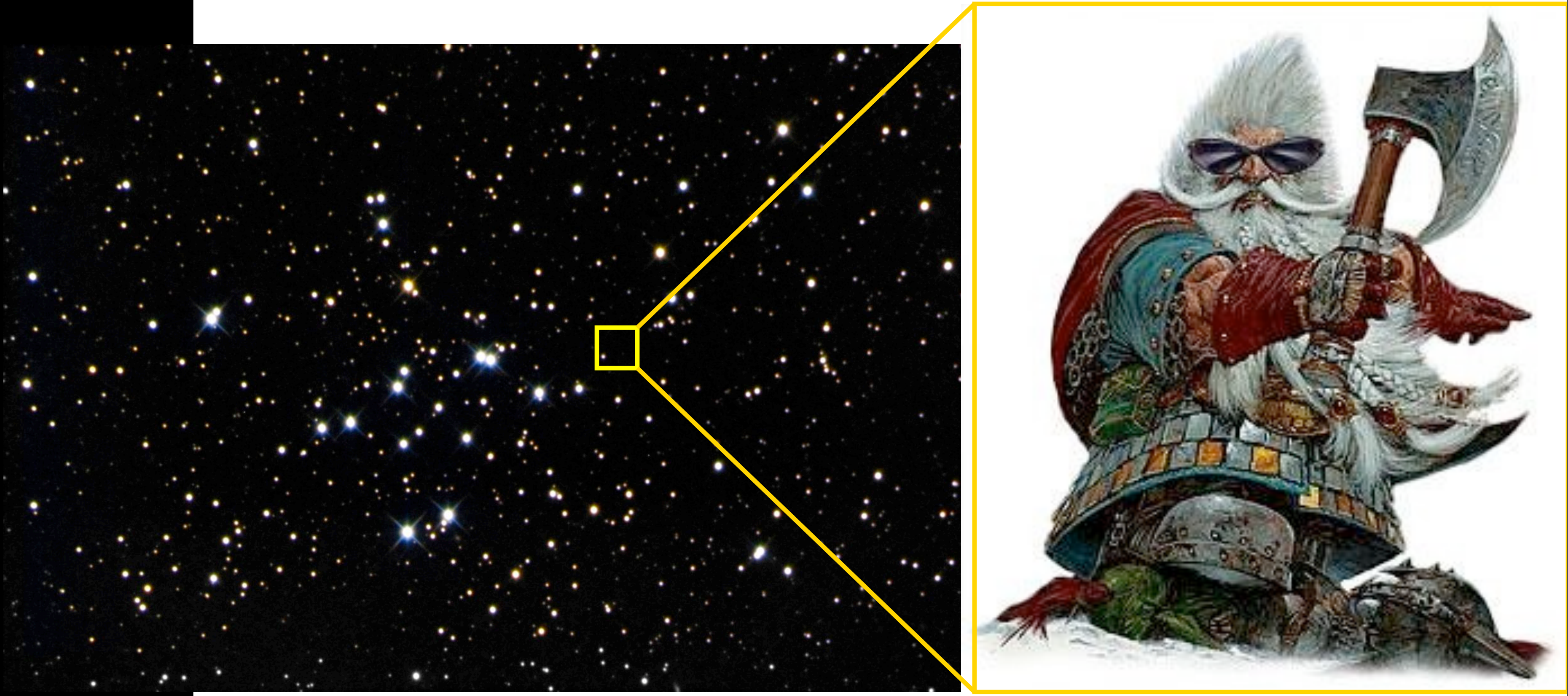

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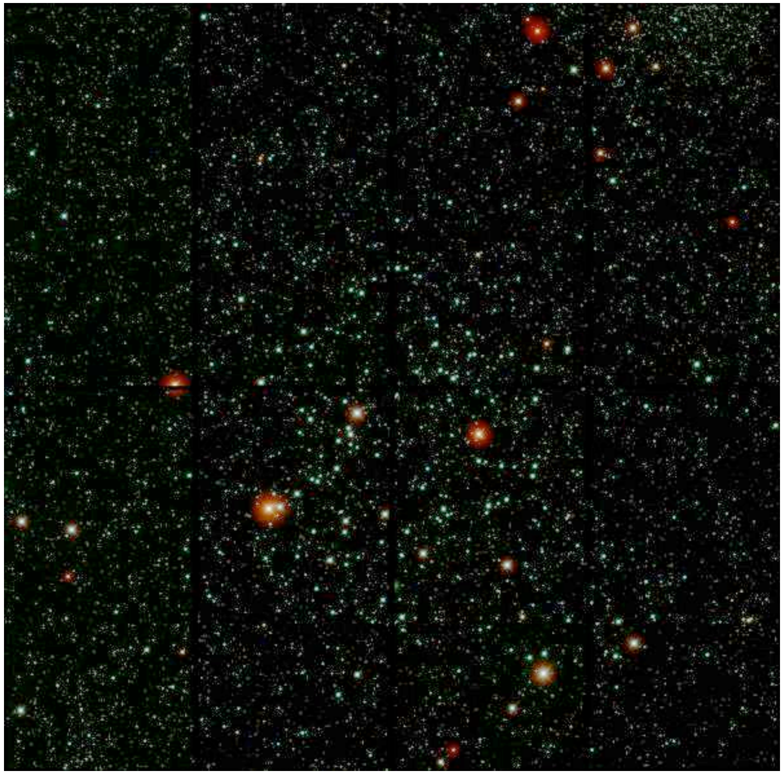
M34: Main Sequence Turnoff Mass~$4M_{\odot}$

Deriving the progenitor masses of white dwarfs involves many model-dependent steps.

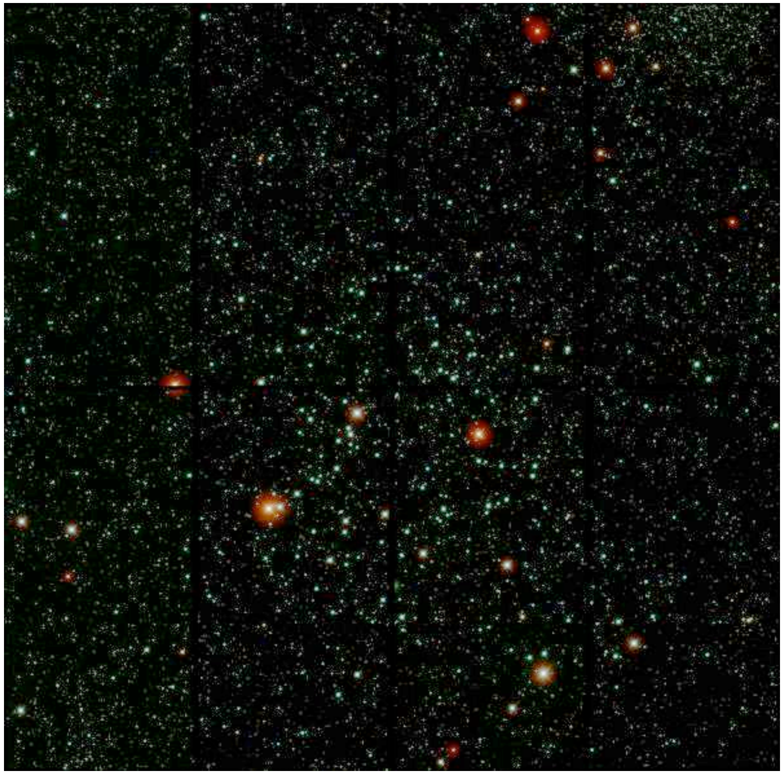


NOAO, K. Williams

Messier 35

Deriving the progenitor masses of white dwarfs involves many model-dependent steps.

Find a white dwarf



NOAO, K. Williams

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Deriving the progenitor masses of white dwarfs involves many model-dependent steps.

Find a white dwarf

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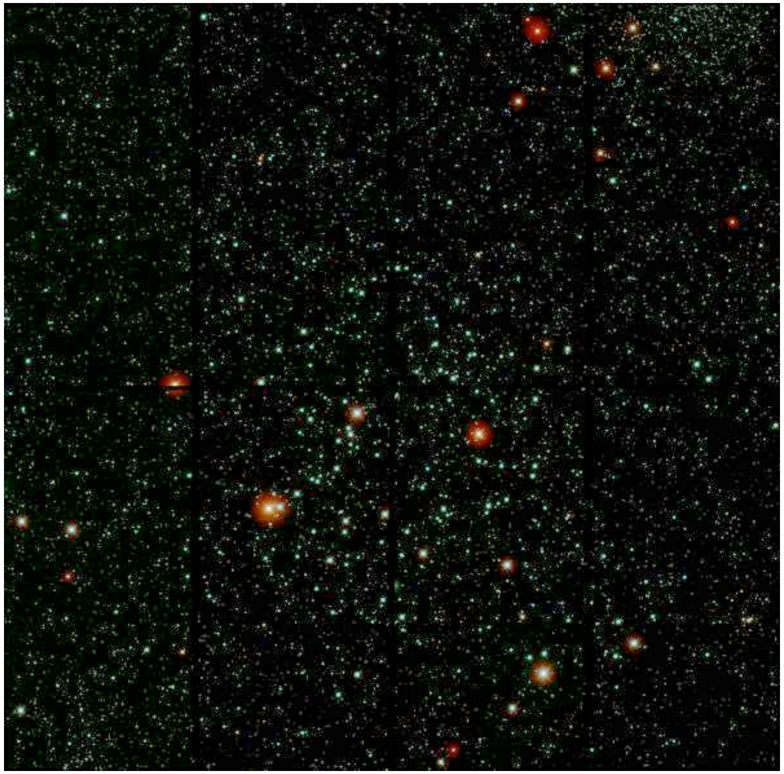
Determine its mass and cooling age



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Deriving the progenitor masses of white dwarfs involves many model-dependent steps.

Find a white dwarf

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Determine its mass and cooling age

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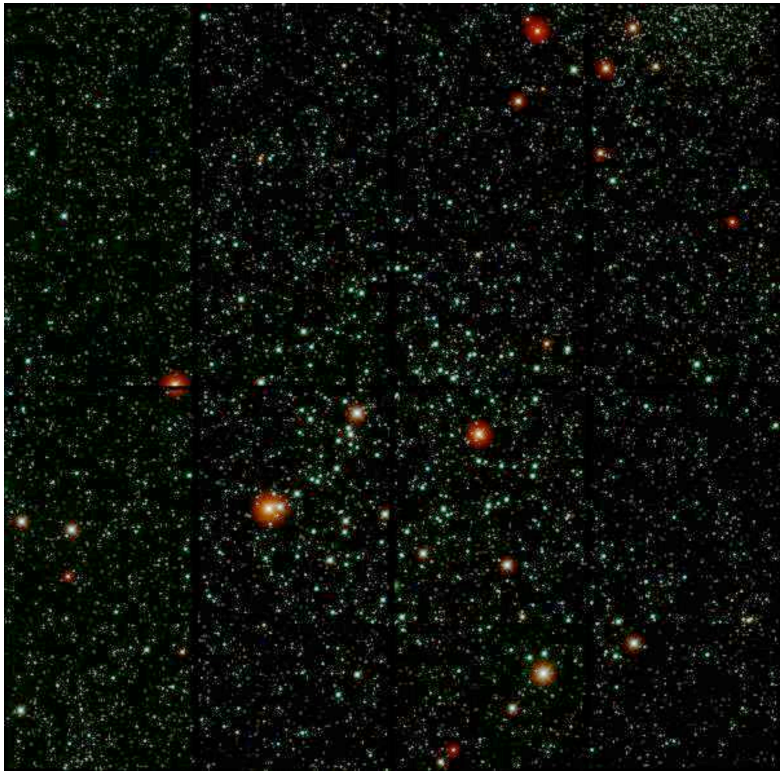
Subtract its cooling age from the cluster age



NOAO, K. Williams

Messier 35

Deriving the progenitor masses of white dwarfs involves many model-dependent steps.

Find a white dwarf

↓

Determine its mass and cooling age

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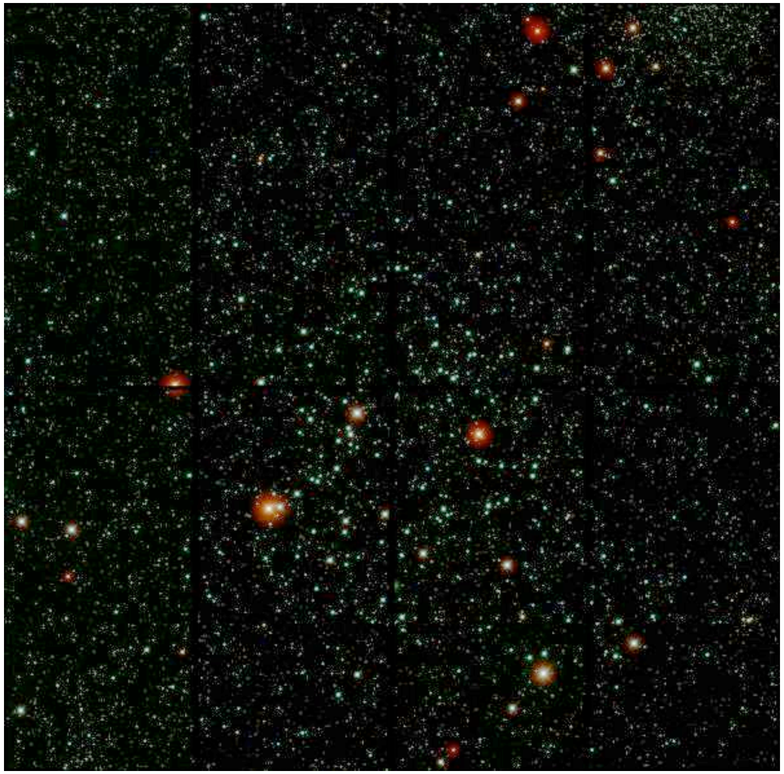
Subtract its cooling age from the cluster age

↓

Use models to get progenitor mass



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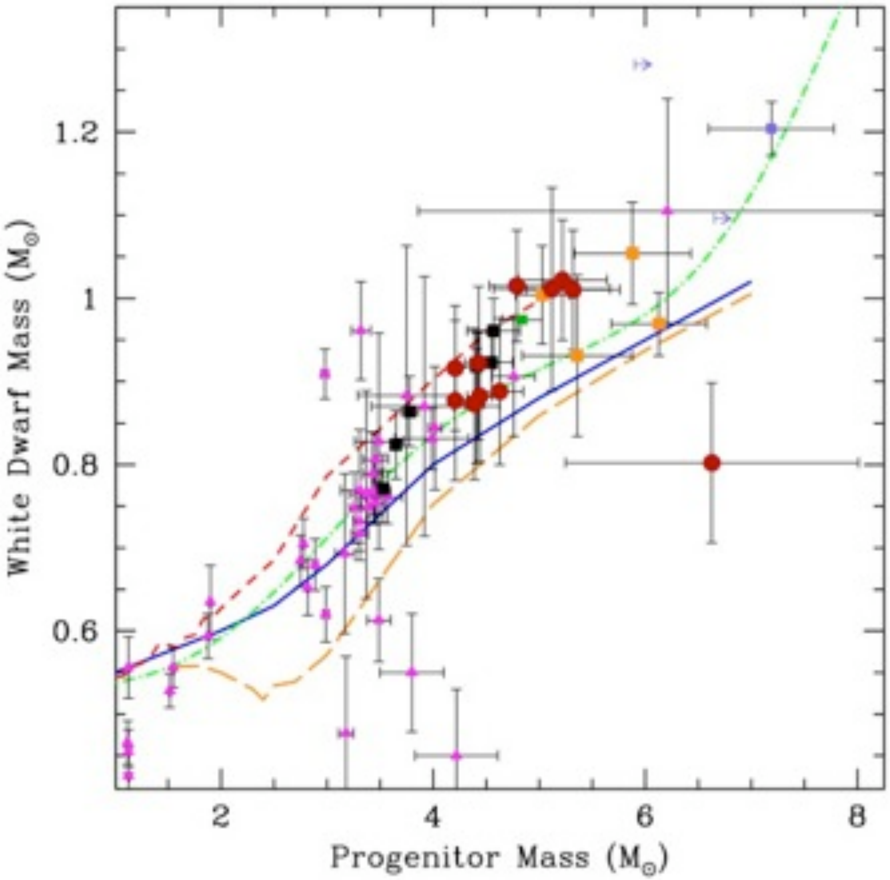
Messier 35

The initial-final mass relation is well-defined and approximates theoretically-derived IFMRs.



Dominguez et al. 1999

Weidemann 2000

Marigo 2007

Ferrario et al. 2005

M35 (Williams et al. 2009)

NGC 2516 (Koester & Reimers 1996; Dobbie & Williams, in prep)

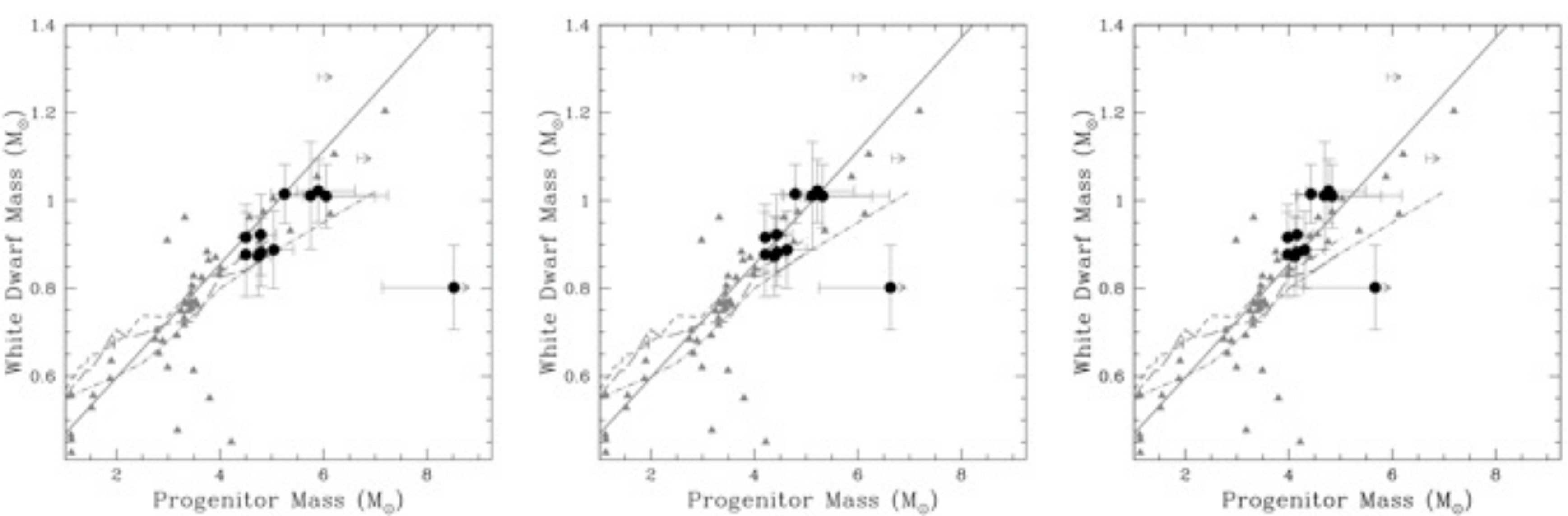
NGC 3532/2287 (Dobbie et al 2009)

Pleiades (e.g., Dobbie et al 2006)

Sirius B (Liebert et al. 2005)

Everything else

The major systematic error for young clusters is the uncertainty in a star cluster’s age.



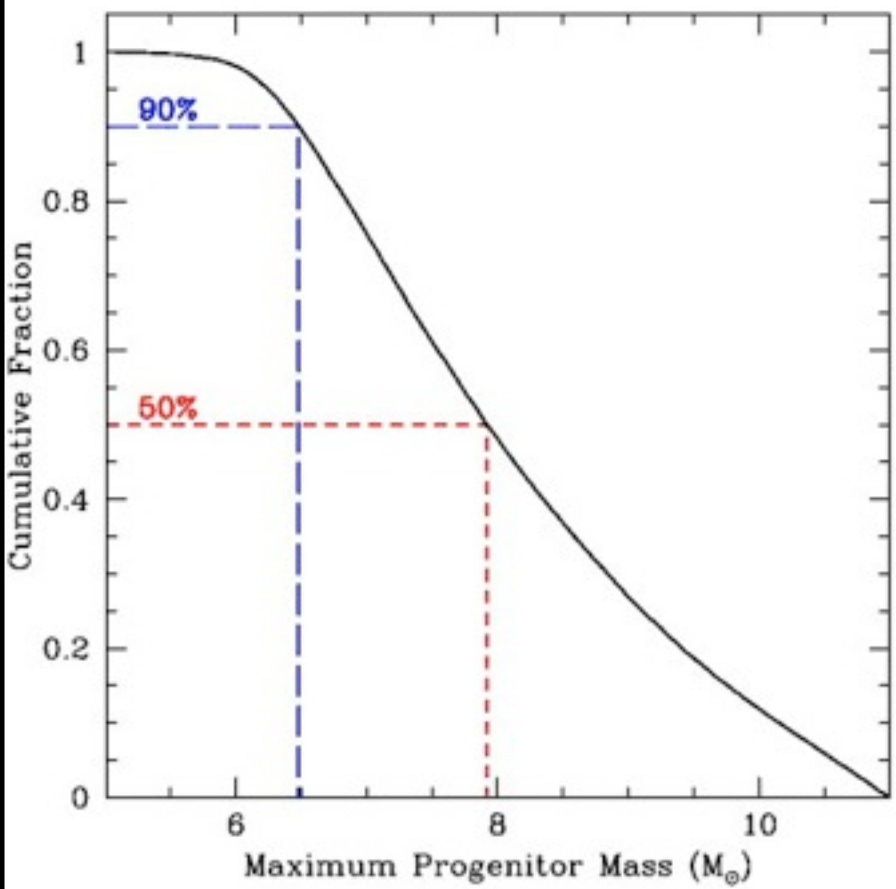
150 Myr

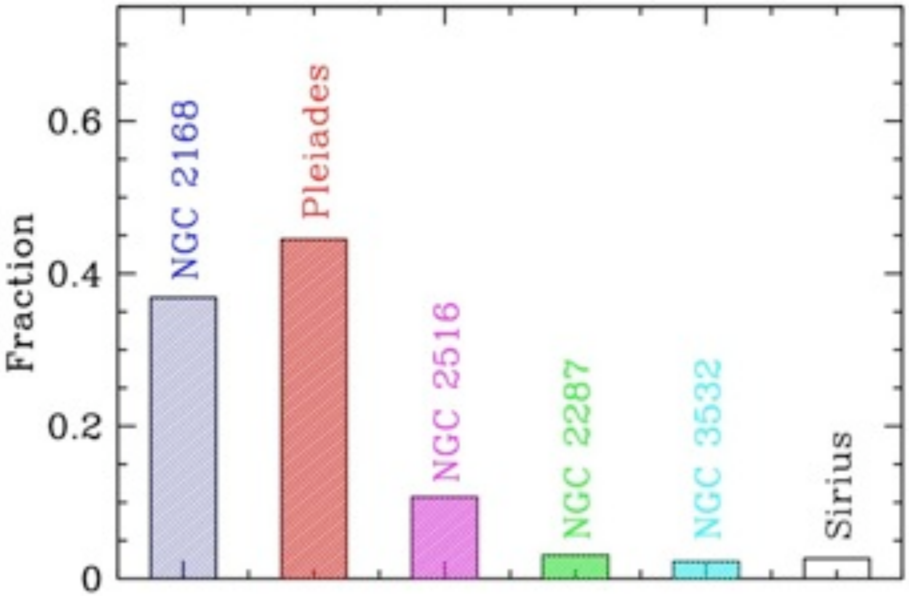
175 Myr

200 Myr

Williams et al. (2009)

A Monte Carlo calculation gives an observational lower limit (90%) on M_W of ~$6.5M_\odot$.

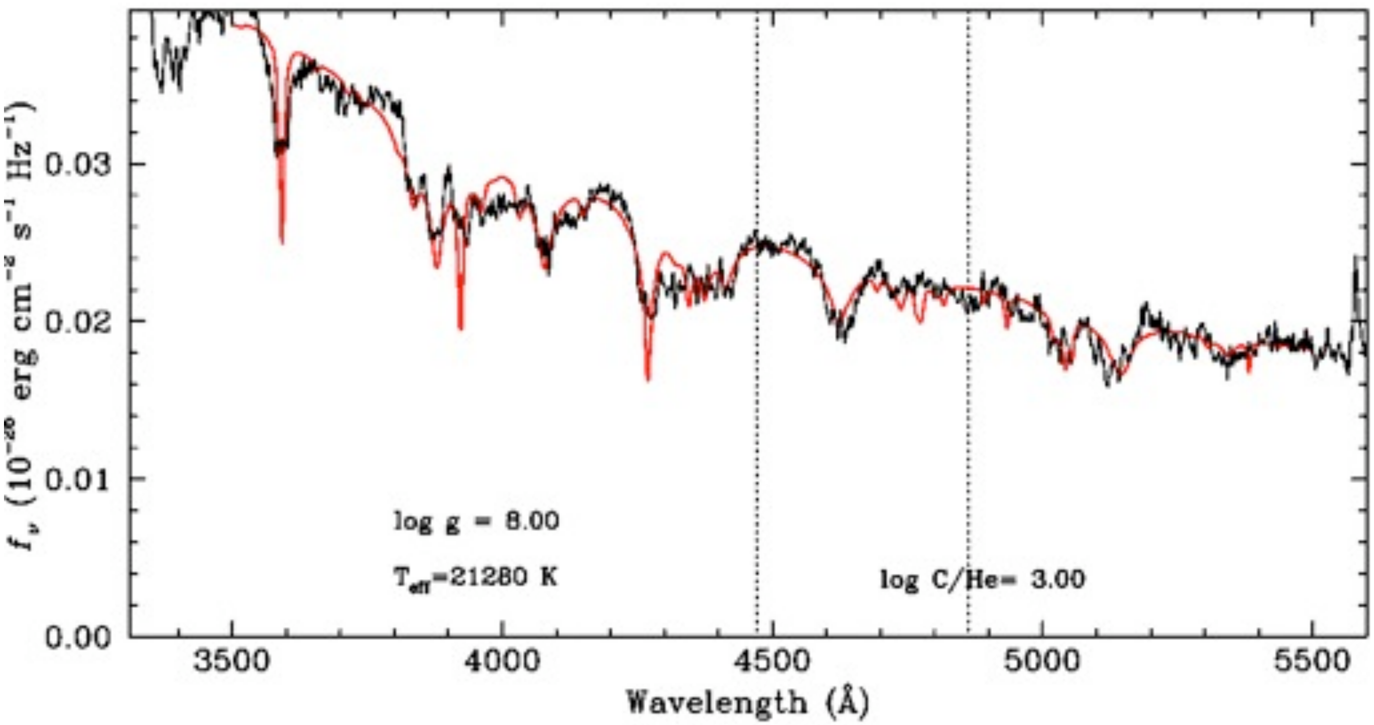




The lower limit on M_W is not highly sensitive to most systematics.

Systematics	90%	50%
Default	6.48	7.92
Z=0.013	6.43	7.90
Include GD50 & PG0136	6.79	8.37
No ONe WDs	6.58	8.29
Include Systematic WD Fitting Errors	6.29	7.83

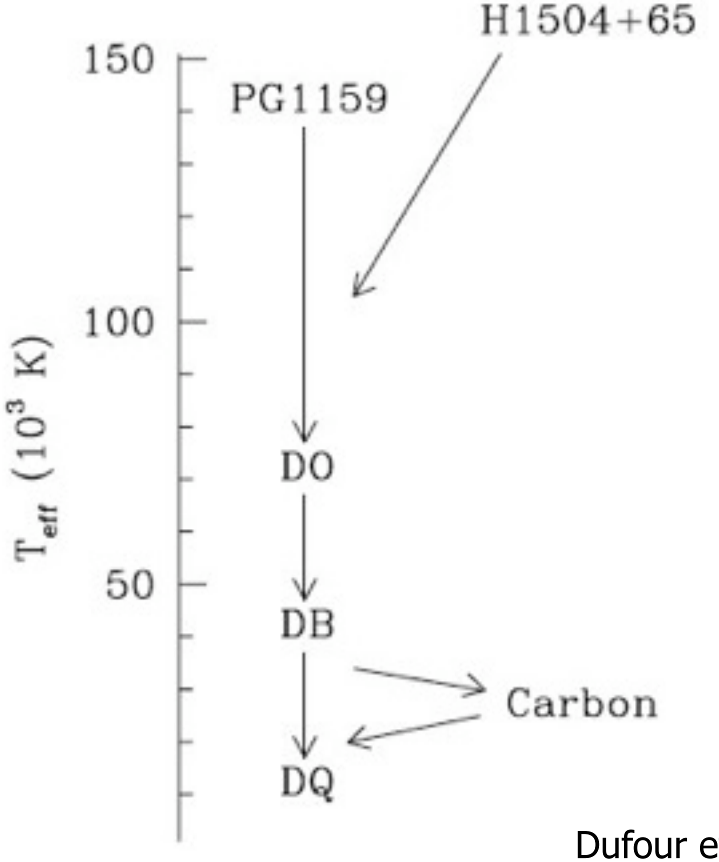
In M35, we found one white dwarf with spectral features of carbon, but no hydrogen or helium.



Williams et al. (2006)

Dufour & Williams, in prep.

In 2007, Patrick Dufour recognized that such white dwarfs, spectral type hot DQ, had (nearly) pure carbon atmospheres.

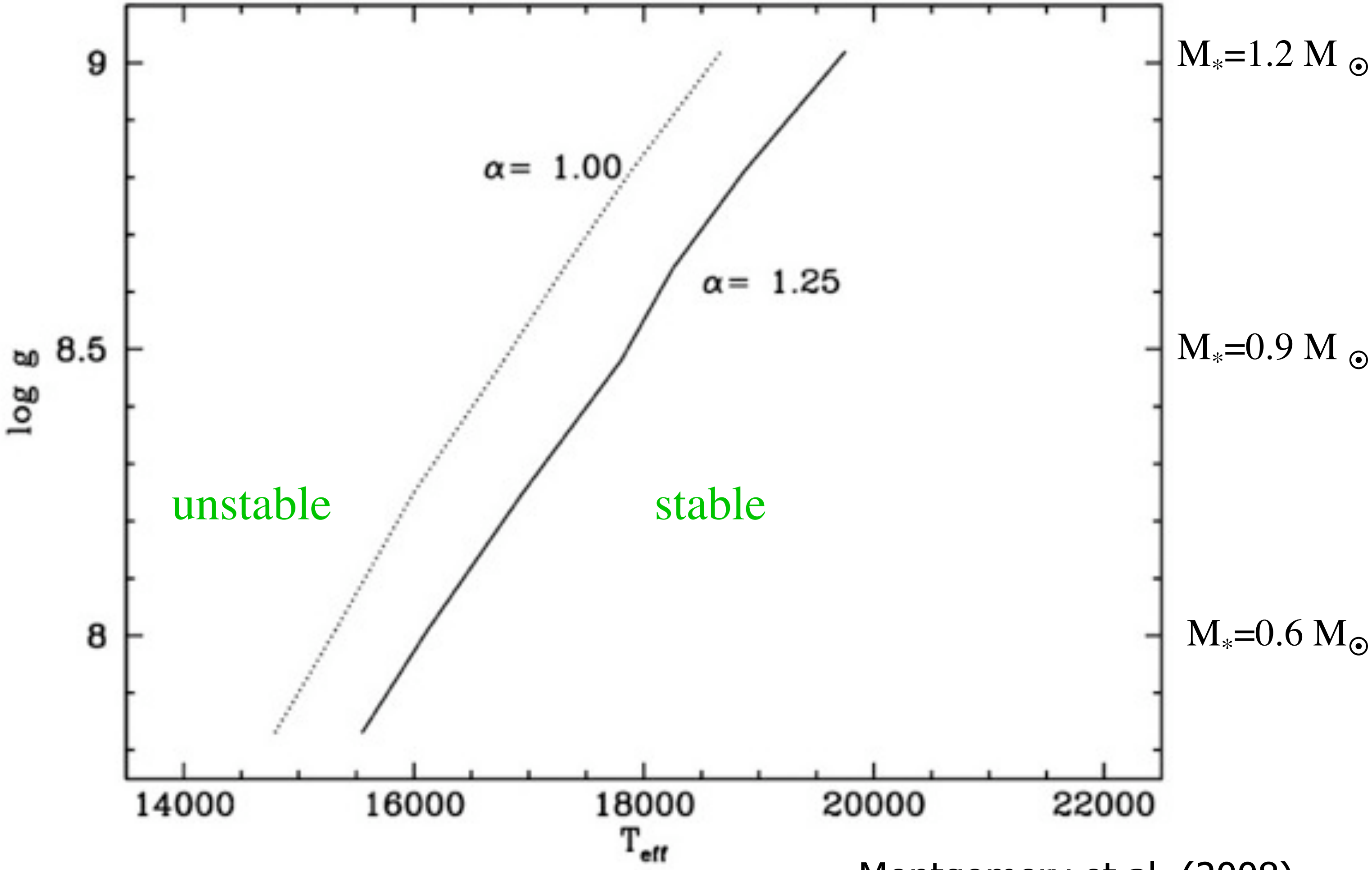


Dufour et al. (2008)

Hot DQ white dwarfs have ensemble properties greatly different from other white dwarfs.

	Hot DQs	Other WDs
Surface Composition	$\log(C/H) > 1.5$ $\log(C/He) > 0$ Dufour et al. (2008)	$\log(C/He) < -2.5$ Dufour et al. (2005)
Mass	$\sim 1M_{\odot}$ (parallax & M35 association; spectroscopic fits come in lower)	$0.6M_{\odot}$ $(85\% < 0.8M_{\odot})$ (e.g., Liebert et al. 2005)
Incidence of Magnetism ($\gtrsim$1MG)	$\gtrsim 50\%$	$<10\%$ (e.g., Liebert 1988)

Pure carbon models can predict the "blue edge" of the instability strip.



Montgomery et al. (2008)

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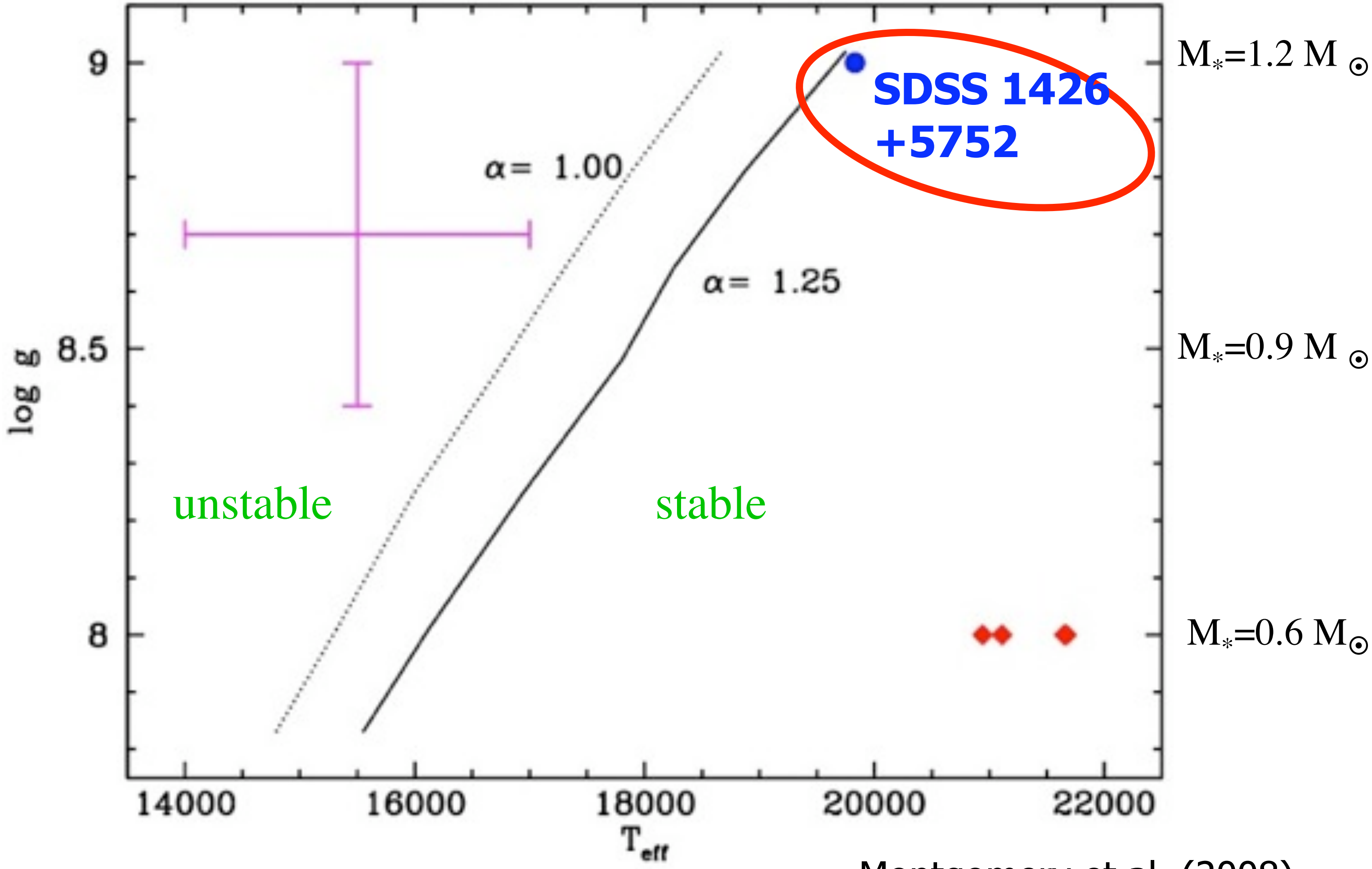

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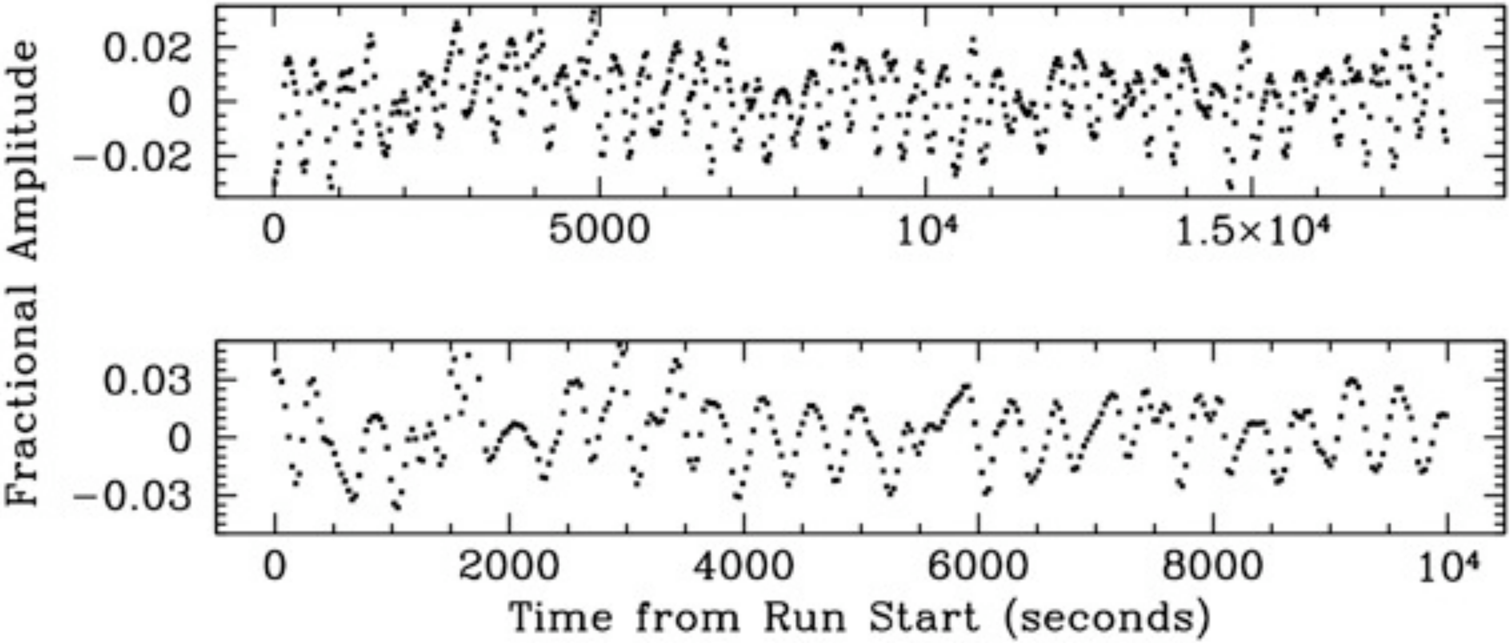

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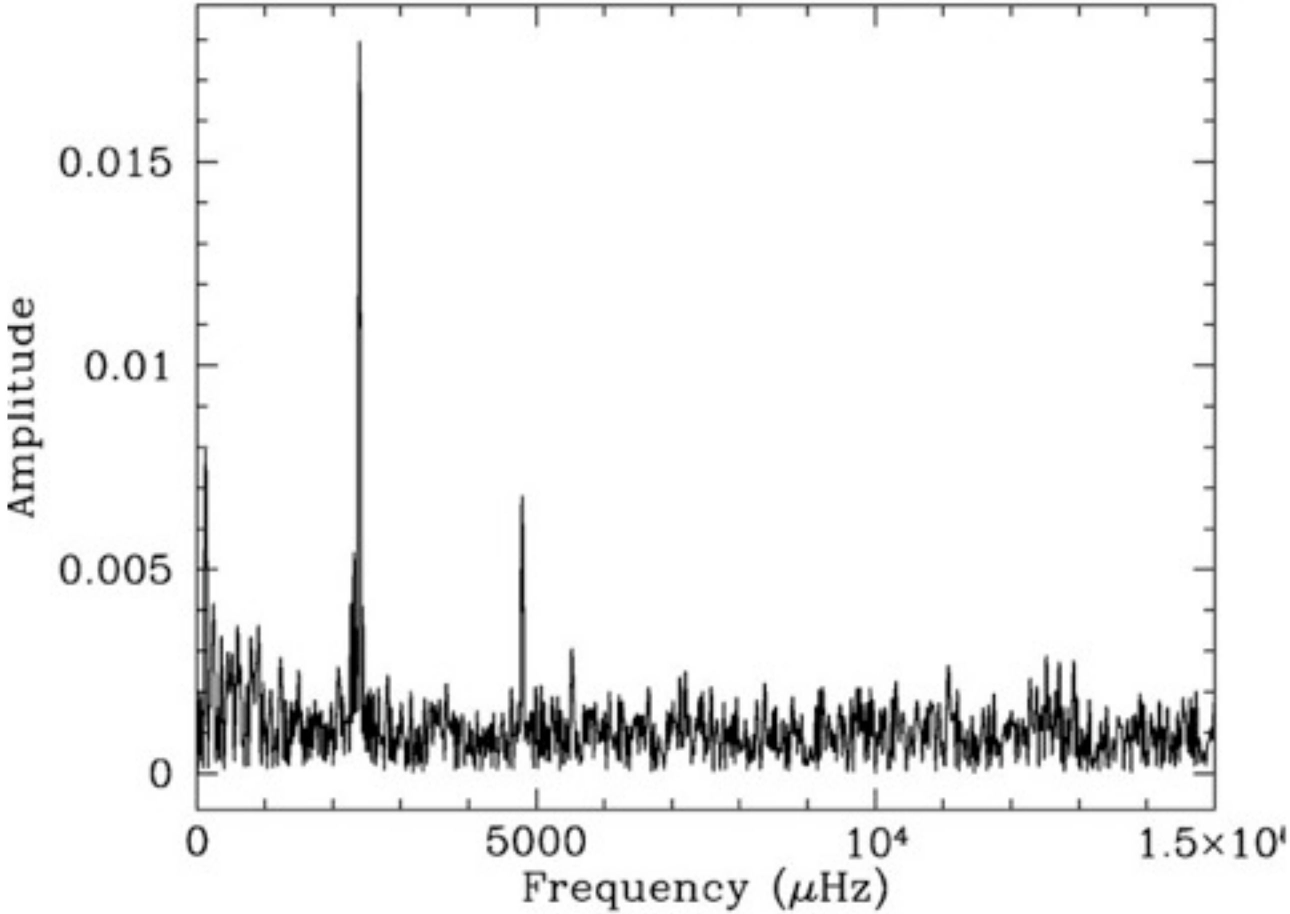
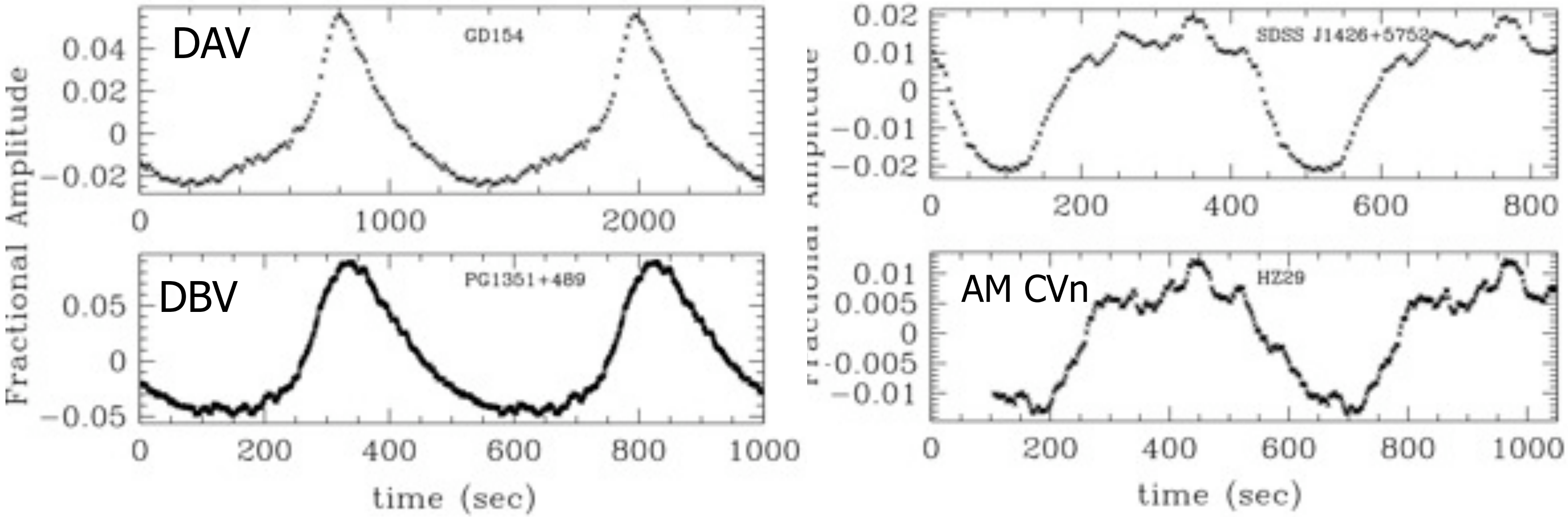


However, the variable DQs (DQVs) may not be ordinary pulsators.



Montgomery et al. 2008

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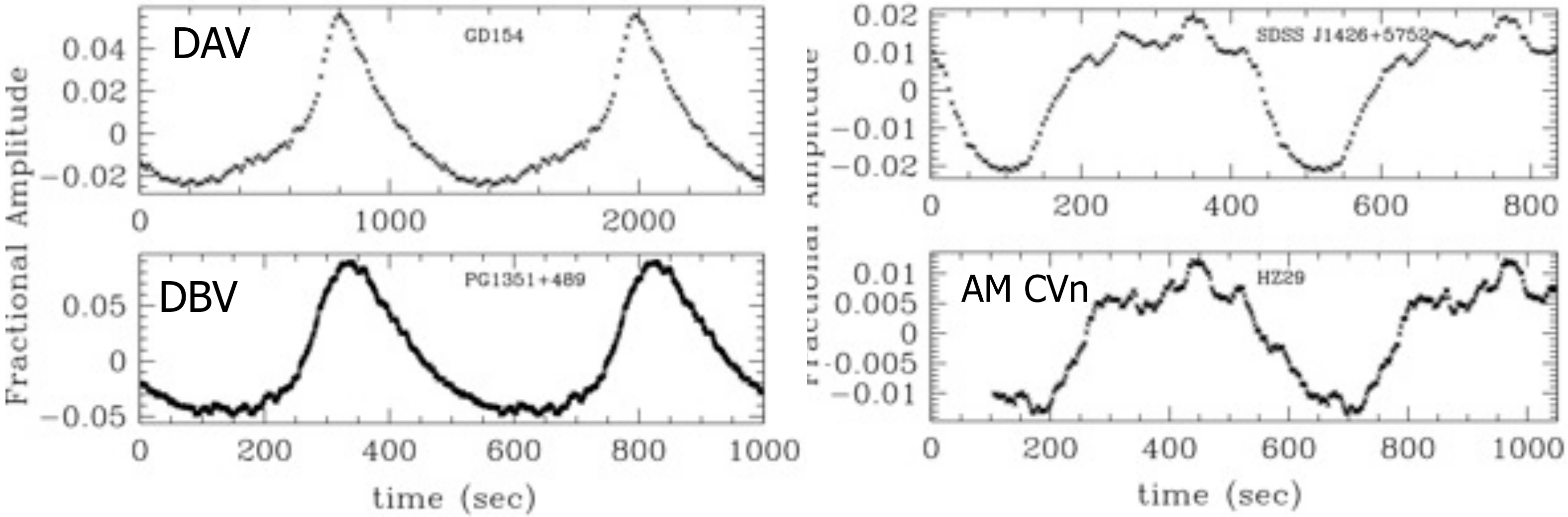

Montgomery et al. 2008

Since last spring, four more DQVs have been found with similar characteristics.

It remains to be proven that the DQVs are indeed pulsating stars, but we prefer that explanation.

Pulsating White Dwarfs

✓Pulsations predicted before variability was discovered

✓Emerging evidence for multiple periodicities

✓Emerging evidence for temperature dependence

✘ Odd pulse shape

✘ Magnetic field (?)

Interacting Binary

✓Pulse shape similarities

✘ No accretion signatures in spectrum

Starspot

✓Can explain pulse shapes and harmonics

✘ No starspots are known on white dwarfs

Where do hot DQs come from?

Born-again scenario (e.g., Althaus et al. 2009)

✓Explains atmospheric composition
✓Explains spectral evolution

✗ Does not require high masses
✗ Does not explain magnetic field

Other clues to the origin:

- The Messier 35 hot DQ, if a cluster member, requires a progenitor mass $>7M_{\odot}$.

- High parallax masses ⇒ high progenitor masses.

Hot DQs *may* arise from the most massive stars to make white dwarfs

Conclusions & Future Work

- White dwarfs give an observational lower limit on M_W, but these limits are very sensitive to observational and model uncertainties.
- Based on available WD observations, $M_W > 6.5\ M_\odot$ (90% confidence).
- Carbon-atmosphere WDs (hot DQs and H1504+65) may be the progeny of 7-11 $M_\odot$ stars
- If the observed variability in many hot DQs is due to standard white dwarf pulsations, asteroseismology should be able to tell us their core composition.